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Scattering of turbulent-jet wavepackets by a flexible composite plate

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Installed jet noise is studied by means of a simplified configuration comprising flat rectangular plates situated in the nearfield of a round jet. Acoustic measurements are performed using a traversable 18-microphone azimuthal array, providing pressure data at 360 points on a cylindrical surface surrounding the jet-plate system. A rigid aluminium plate and a flexible, composite plate were tested to assess the influence of the plate stiffness on the scattered sound. The numerical predictions are confirmed by experiments and suggest that a reduction in the scattered sound level can be achieved as the flexibility of the plate is increased.

I. Introduction

The sound radiation associated with the proximity of a solid surface to a turbulent jet, known as installation noise, has been recognised to be an important noise source for High and Ultra-High ByPass Ratio engine configurations. The large sound amplification observed in directions normal to the surface of the wing at high polar angles, has been demonstrated[1] to be imputed to the scattering by the trailing edge.

Recent studies[2] showed that a swept trailing edge is an effective way to obtain a reduction in the amplification lobes due to the plate. Scattering has also been shown to be reduced as the plate elasticity is modified such that a beneficial interaction occurs between bending and acoustic waves.[3,4] More recently, Cavalieri et al[5] developed a numerical method, based on the resolution of a Boundary Element Method (BEM), that accounts for the presence of a composite, anisotropic plate in the vicinity of the jet. Elasticity effects lead to reductions of the scattered sound for both aluminum and composite plates. However, the latter were seen to lead to more significant reductions of acoustic scattering compared to the former, because of their lower specific mass, which allow higher bending-wave amplitudes.

In the present work, we experimentally study the scattering of a composite rectangular plate, and we compare this with model predictions for both 1D and 2D plates. While the 1D plate model suggests sound reductions at a given level of flexibility, the 2D model shows that for the same flexibility very little sound reduction can be achieved. The experimental measurements confirm this, validating the model, which, furthermore, suggests that increased flexibility is necessary in order to produce significant sound reduction.

The paper is organised as follows. The numerical model and prediction are presented in section II. In section III the experimental setup is presented as well as the composite plate characteristics. Some results from the comparison between the rigid and composite plate are then highlighted in section IV. This is followed by some conclusions.

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II. Modelling

The numerical formulation developed by Cavalieri et al,[5] based on the solution of a Boundary Element Method (BEM), accounts for the presence of a composite, anisotropic plate. The acoustic problem is characterised by the inhomogeneous Helmholtz equation,

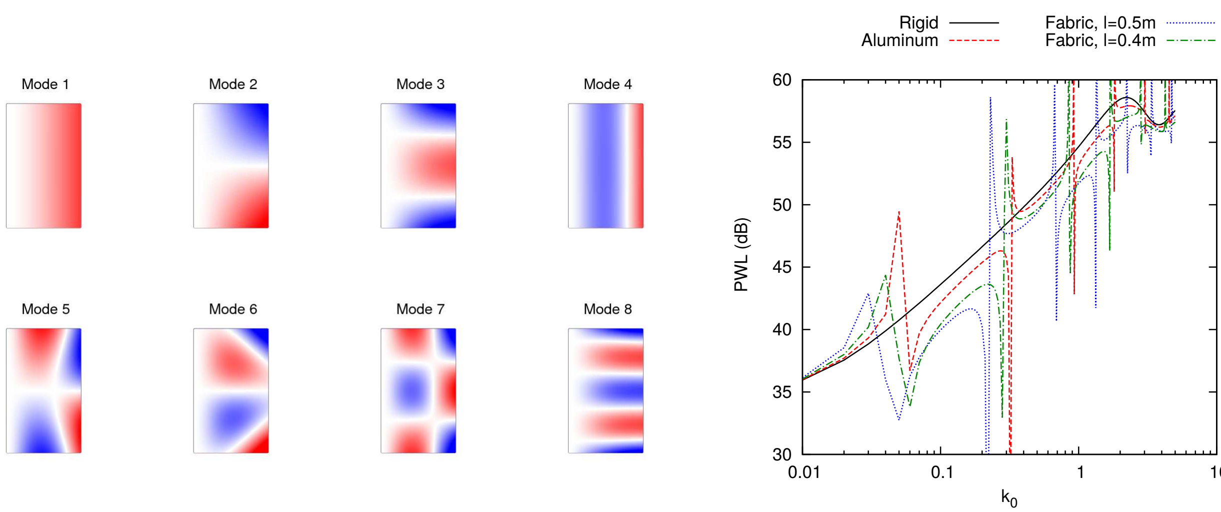
$$\nabla \tilde{p} + \tilde{k}_0 \tilde{p} = \tilde{S} \tag{1}$$

where $\tilde{k}_0$ is the acoustic wavenumber, given as $\tilde{\omega}/\tilde{c}_0$ for angular frequency $\tilde{\omega}$ and speed of sound $\tilde{c}_0$. The acoustic source is represented by an analytical wavepacket-like volume source: a convected wave enclosed in a gaussian envelope whose characteristics are obtained from linear stability calculations. The problem is closed with boundary conditions given by the structural problem: plate and fluid velocity must match at the plate surface. A non-slip condition is applied in the case of a rigid surface, but as the plate is considered as flexible, the pressure difference between the upper and lower surfaces caused by the presence of the jet, excites its natural vibration and thus a non-zero velocity at the plate surface. The first 8 vibrational modes for the composite plate are shown in figure 1(a). The equation for an unsteady load applied to a plate is given, in general form, as

$$\tilde{D}_{11}\mathcal{L}(\tilde{\eta}) - \tilde{m}\tilde{\omega}^2\tilde{\eta} = \Delta\tilde{p} \tag{2}$$

where $\tilde{\eta}$ is the plate displacement, $\tilde{D}_{11}$ is the plate bending stiffness following the x axis, $\mathcal{L}$ is a linear operator involving up to fourth-order spatial derivatives, $\tilde{m}$ is the plate specific mass and $\Delta\tilde{p}$ is the applied load, given by the pressure difference between lower and upper surfaces. The BEM solver is then able to directly solve the coupled problem.

Figure 1(b) shows results for different 1D plates: the rigid one, a flexible aluminium plate, characterised by isotropic behaviour, and the composite cross-ply plate. The PWL is plotted as function of the Helmholtz number $k_0 = \omega L c_0$. Resonance peaks are present for the flexible plates and can lead to both an increase and a reduction of the scattered sound depending on the relative phase of excitation and vibration. We consider a Strouhal number of $St = 0.2$, for which the corresponding Helmholtz number for the jet at study is $k_0 = 2\pi StML/D = 6$, where M is the jet Mach number, L the plate chord and D the jet diameter. At this particular condition the predicted sound level is reduced of about $3dB$ with respect to the rigid limit.



(a) (b)

Figure 1. (a) 2D plate vibrational modes; (b) Composite 1D plate response as function of Helmholtz number k_0.

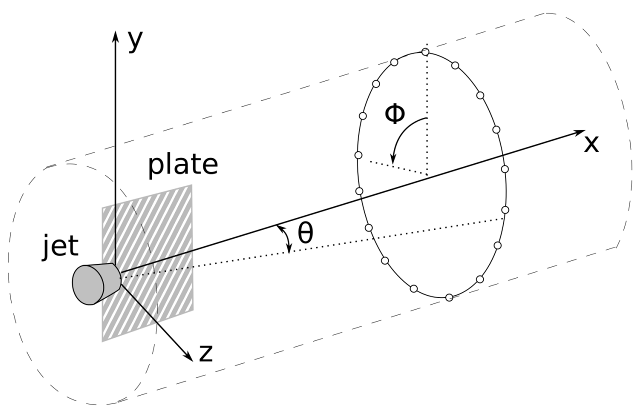
III. Experimental setup

The experiments were performed in the *Bruit et Vent* anechoic facility of the PPRIME Institute, Poitiers, France. The nozzle, of diameter, $D = 0.05$ m, is the same used in a number of previous papers[6–9] where the

flow and sound fields have been extensively studied in both uninstalled and installed configurations, for the Mach number range $0.4 \leq M \leq 0.6$.

Acoustic measurements were previously made[2] for the $M = 0.6$ jet and for the aluminium plate case, by means of an 18-microphone azimuthal array, of radius $r/D = 14.3$, whose axial position is varied so as to map the sound field on a cylindrical surface containing the jet-wing system. The axial measurement range is $-1.3 \simeq x/D \simeq 39$; a total of 360 microphone measurements are made. A second set of measurements was obtained for the composite plate configuration (figure 2(b)). The plate has an edge clamped to the support, while the other edges are free to vibrate. More details on the plate characteristics are found in the following.

In both cases, the plate has dimensions $L = 450mm, H = 750mm$ ($9D \times 15D$) and its flat surface was mounted parallel to the jet, at a radial distance from the jet axis that we varied from $r/D = 1$ to $r/D = 2$. The mid-span of the trailing edge is situated at $x/D = 4$ from the jet exit plane. A sketch of the experimental layout is provided in figure 2(a), including the reference coordinate system and polar (θ) and azimuthal (Φ) angle conventions used. The azimuthal angle of the microphones, is measured counterclockwise (with respect to the positive x-axis) from the top of the antenna. In this reference system, azimuthal angles $0° \leq \phi \leq 180°$ correspond to the shielded side of the plate, while $180° \leq \phi \leq 360°$ correspond to the unshielded side.



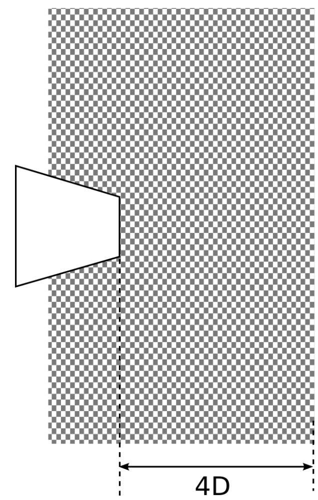


Figure 2. Experimental layout.

A. Composite plate

We consider in this study an anisotropic composite plate, composed of 8 different layers of carbonium laminae, symmetric about the middle plane, such that there is no coupling between bending and extension, oriented with an angle of 0° and 90° with respect to the chordwise direction, as summarised in table 1. The plate has a thickness of $h = 1.12mm$ ($0.0224D$). The mechanical characteristics of the considered plate are reported in table 2.

Laminate	Lay-ups
Cross-ply	[0/90/0/90/90/0/90/0]

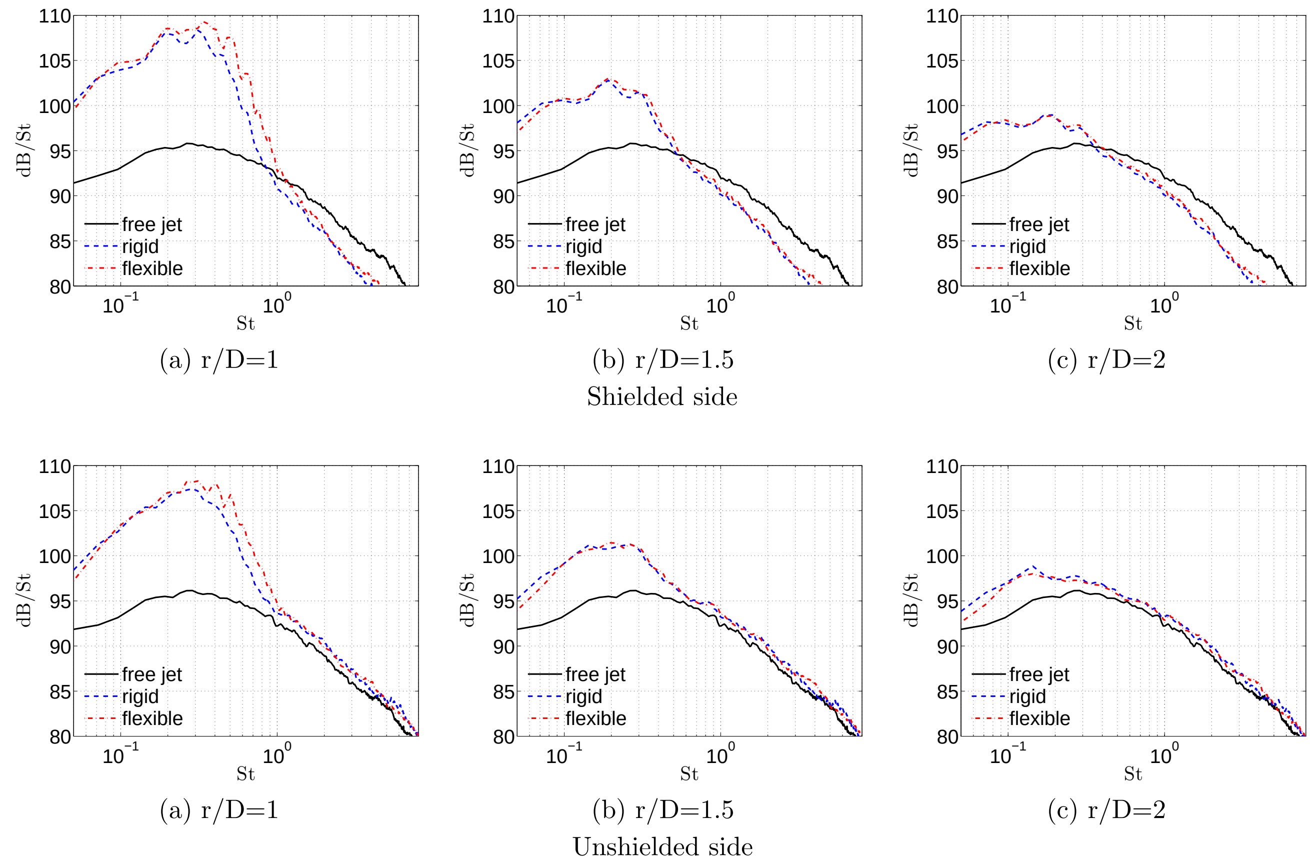
Table 1. Composite plate composition.

Plate	$D_{11}(N \cdot mm)$	Ω (rad/s)	$\omega_c h/c_0$	ϵ_0
Cross-ply	6090	0.295	0.19382	0.00466

Table 2. Bending stiffness and fluid-structure parameters of the composite plate at study.

IV. Results

We show comparisons between the aluminium and composite plates. Figure 3, showing a comparison between the sideline spectra for the aluminium and composite plates when the jet-plate radial distance is varied, shows for radial positions $r/D = 1.5\&2$ a negligible effect of the flexibility on the low-frequency scattered sound, for both the shielded and unshielded sides. For the closest radial position, $r/D = 1$, on the other hand a sound increase is observed over the range $0.2 \leq St \leq 1.5$. We suspect that this increase may be due to a stronger interaction between the plate and the jet due, on one hand, to a mean radial displacement of the plate produced by the jet, and, on the other, to the high amplitude of the plate vibration, which leads to associated fluctuation of the level of the grazing flow. As the plate is moved radially outward, these effects become less important, and the measurements show that the 2D composite plate produces negligible sound reduction.



(a) r/D=1 (b) r/D=1.5 (c) r/D=2

Shielded side

(a) r/D=1 (b) r/D=1.5 (c) r/D=2

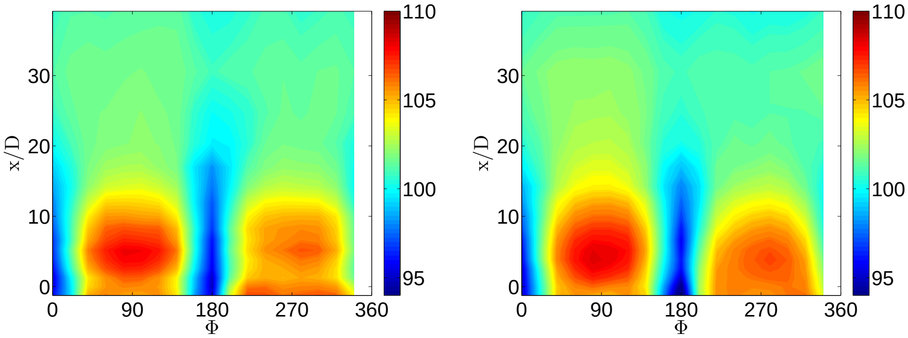
Unshielded side

Figure 3. Spectra for installed jet for different radial position of the plate.

PSD maps at St=0.2, as a function of azimuthal angle and axial position, are shown in figure 6 and compared with the model prediction for the 2D plate. Two main lobes of high intensity appear in the sound field in the sideline direction, giving the typical directivity pattern of the installed configuration. The BEM calculation predicts a negligible effect of the flexibility for the 2D composite plate (bottom figures), and this is confirmed by experiments (top).

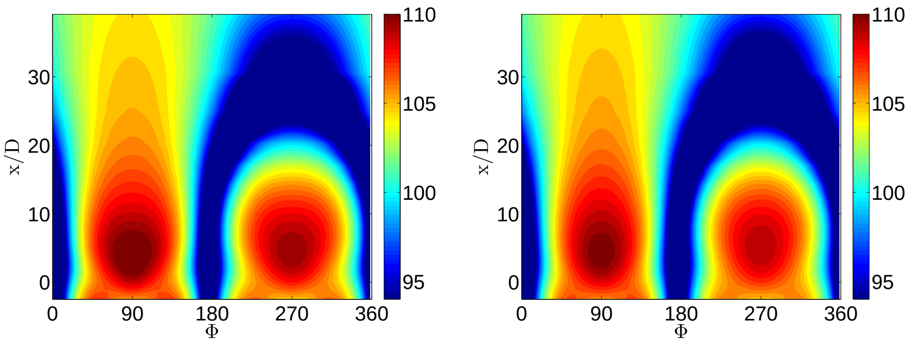
A. Flexibility effect

The BEM calculation allows us to test plates with different flexibility characteristics. We change the bending-wave Mach number Ω,considering 2 composite plates with $\Omega = 0.1$ and $\Omega = 0.2$. A comparison between BEM results for the rigid and the 3 flexible plates are shown in figure 6. A significant noise reduction can be achieved as the flexibility is increased. Such plates will be considered experimentally in future studies.



(a) rigid plate (b) flexible plate

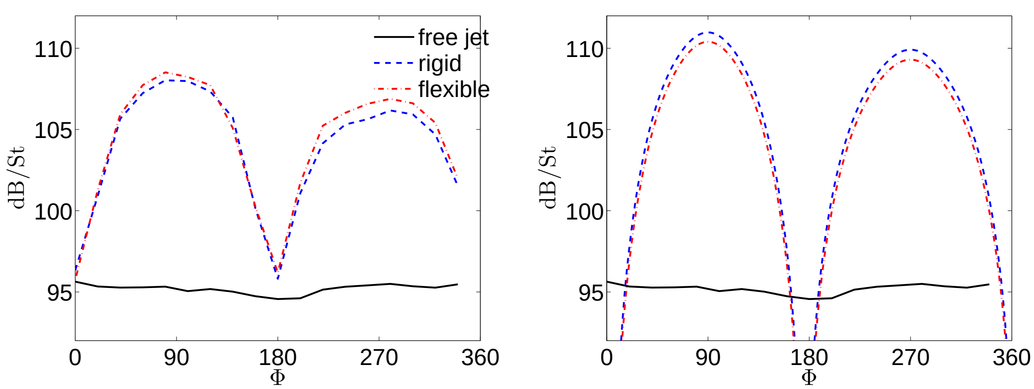
Experimental results



(a) rigid plate (b) flexible plate

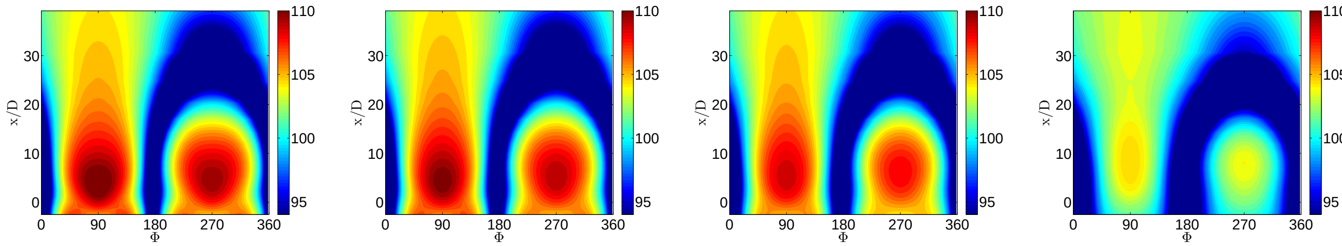
BEM results

Figure 4. PSD maps for installed jet at St=0.2.



(a) Experimental results (b) BEM results

Figure 5. Azimuthal directivity for installed jet, St=0.2, x/D=4.



(a) rigid plate (b) $\Omega = 0.295$ (c) $\Omega = 0.2$ (c) $\Omega = 0.1$

Figure 6. BEM results at St=0.2 for plates with different flexibility parameter.

V. Conclusions

We studied the installed jet problem, where a flexible, anisotropic carbon plate is placed in the nearfield of a subsonic turbulent jet. Flexibility is known to have a beneficial effect on the noise scattering by the plate trailing edge. A 1D composite plate model predicted noise reductions for a given level of flexibility. Based on this a 2D plate was built and tested experimentally. Negligible noise reduction was observed, consistent with subsequent model predictions for a 2D plate. The model predicts noise reductions for higher flexibility of the 2D plate in comparison with its 1D counterpart. Future studies will involve experiments using plates of higher flexibility, as suggested by 2D-plate-model predictions.

VI. Acknowledgements

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